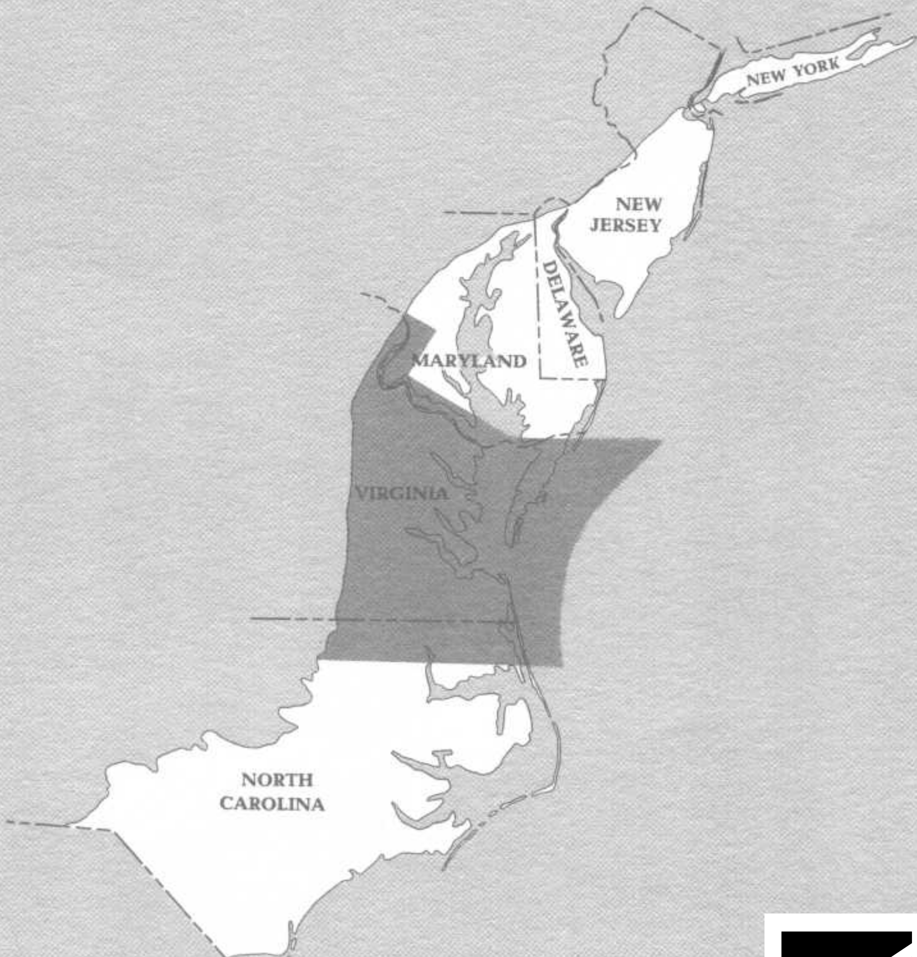
CONCEPTUALIZATION AND ANALYSIS OF GROUND-WATER FLOW SYSTEM IN THE COASTAL PLAIN OF VIRGINIA AND ADJACENT PARTS OF MARYLAND AND NORTH CAROLINA

REGIONAL AQUIFER-SYSTEM ANALYSIS



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Use of ground water from confined aquifers began in the Virginia Coastal Plain in the late 1800's and had increased to about 100 Mgal/d in 1980. The continued withdrawal of large quantities of water has resulted in a steady decline of water levels. The decline has changed the direction of ground-water flow toward major pumping centers. These centers are located near the cities of Franklin, Williamsburg, Suffolk, and Alexandria and the towns of West Point and Smithfield. Total withdrawal from these centers is estimated to have been 65 Mgal/d in 1980. The largest center is near Franklin, where withdrawals exceeded 40 Mgal/d in 1980.

A digital flow model was developed to simulate the response of the ground-water flow system to ground-water development. Withdrawal data for each confined aquifer were compiled for the period of simulation, 1891–1980. The middle Potomac aquifer is the most important source of ground water in the Virginia Coastal Plain and supplied an average of about 56 Mgal/d during the period 1978–80. The transmissivity distribution was defined for each aquifer; in general, transmissivity increases from the Fall Line eastward but decreases farther eastward near the freshwater-saltwater interface. The lower and middle Potomac aquifers are the most transmissive aquifers; estimated transmissivity ranges from 410 to 18,145 ft^2/d for the middle Potomac aquifer and from 250 to 12,440 ft^2/d for the lower Potomac aquifer. Vertical leakances simulated the effects of confining units on vertical flow between aquifers.

Maps showing simulated prepumping potentiometric surfaces indicate regional movement of water from the Fall Line toward coastal areas and local movement of ground water from interfluves toward major river valleys. Maps showing simulated flow across confining units indicate that most recharge occurred in narrow bands approximately parallel to the Fall Line and under interfluves and that discharge was toward major river valleys and coastal water. Simulated prepumping rates of recharge into the confined flow system varied up to 3.2 in/yr, and rates of discharge varied up to 2.8 in/yr. The highest rates of simulated recharge are concentrated along the Fall Line.

The simulated potentiometric-surface maps of the major aquifers for 1980 show the lower water levels and the cones of depression that are developing around major pumping centers. The largest simulated decline, about 210 ft, is near Franklin. Water budgets indicate that over the period of simulation (1891–1980) (1) pumpage from the model area increased by about 105 Mgal/d, (2) lateral boundary outflow increased by about 5 Mgal/d, (3) ground-water flow to streams and coastal waters decreased by about 107.5 Mgal/d, (4) lateral boundary inflow increased by about 0.7 Mgal/d, and (5) water released from aquifer storage increased by about 1.6 Mgal/d. Changes in the direction of vertical leakage toward major pumping centers resulted from ground-water withdrawal. The major source of recharge replacing the water pumped from confined aquifers was vertical leakage.

Simulated rates of flow into the confined aquifer system in 1980 varied up to 3.8 in/yr, and rates of flow out of the confined flow system varied up to 2.2 in/yr. Simulations show a net increase of about 110 Mgal/d into the confined from the unconfined flow system over the period of simulation. This change in leakage affected the local discharge of ground water to streams and the regional discharge of ground water to coastal water. The withdrawal of ground water from the confined aquifers increased the area of recharge into the confined flow system by about 33 percent and resulted in the movement of brackish water from Chesapeake Bay into the confined flow system.

Sensitivity analysis shows that simulated water levels are more sensitive to decreases in aquifer transmissivity and confining unit vertical hydraulic conductivity than to increases for the values tested. Lowering the storage coefficient has a negligible effect on simulated water levels; however, increasing the storage coefficient has a significant effect. Sensitivity simulations also indicate that the effect of confining unit storage is not significant if the water released from storage in the confining unit is from the compressibility of water only.

The calibrated model is suitable for analyzing the regional flow of ground water through the confined aquifers. The large grid scale limits the capability of the model to provide a detailed local analysis of the ground-water flow system. The adequacy of the model is governed by estimates of hydraulic characteristics, grid spacing, and time intervals of the 10 pumping periods. The method developed for simulating flow in the water-table aquifer provides an adequate upper-boundary condition for this study. Additional data on streambed leakance, stream base flow, and withdrawal from the water-table aquifer are needed to simulate water levels in the water-table aquifer more accurately and to quantify flow between the water-table aquifer and streams locally. More detailed data are needed to define the time-dependent stresses and the transient effect due to the release of water from storage in the confining units that is neglected in the model developed for this study.

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TABLES 1–13

TABLE 1.—*Relation of stratigraphic formations and hydrogeologic units of the Virginia Coastal Plain*
[Modified from Meng and Harsh, 1988]

Geologic age		Stratigraphic formation	Hydrogeologic unit
Period	Epoch		
Quaternary	Holocene	Holocene deposits	Columbia aquifer
	Pleistocene	Undifferentiated deposits	
Tertiary	Pliocene	Yorktown Formation	Yorktown confining unit
			Yorktown-Eastover aquifer
	Miocene	Eastover Formation	
			St. Marys confining unit
		St. Marys Formation	St. Marys-Choptank aquifer
		Choptank Formation	
		Calvert Formation	Calvert confining unit
	Oligocene	Old Church Formation	Chickahominy-Piney Point aquifer
	Eocene	Chickahominy Formation	
		Piney Point Formation	
		Nanjemoy Formation	Nanjemoy-Marlboro Clay confining unit
		Marlboro Clay	
	Paleocene	Aquia Formation	Aquia aquifer
		Brightseat Formation	Brightseat-upper Potomac confining unit
Cretaceous	Late Cretaceous	Potomac Formation	Brightseat-upper Potomac aquifer
			Middle Potomac confining unit
			Middle Potomac aquifer
	Early Cretaceous		Lower Potomac confining unit
			Lower Potomac aquifer

TABLE 2.—*Correlation of hydrogeologic units of Maryland, Virginia, and North Carolina and corresponding layers used in the flow model*

[AQ, aquifer; CU, confining unit]

Maryland hydrogeologic unit	Virginia hydrogeologic unit	North Carolina hydrogeologic unit	Flow-model layer
Surficial aquifer	Columbia aquifer	Surficial aquifer	AQ10
Upper Chesapeake confining unit	Yorktown confining unit	Confining unit	CU9
Upper Chesapeake aquifer	Yorktown-Eastover aquifer	Yorktown aquifer	AQ9
St. Marys confining unit	St. Marys confining unit	Confining unit	CU8
Lower Chesapeake aquifer	St. Marys-Choptank aquifer	Pungo River aquifer	AQ8
Lower Chesapeake confining unit	Calvert confining unit	Confining unit	CU7
Piney Point-Nanjemoy aquifer	Chickahominy-Piney Point aquifer	Castle Hayne aquifer	AQ7
Nanjemoy-Marlboro confining unit	Nanjemoy-Marlboro confining unit	Confining unit	CU6
Aquia-Rancocas aquifer	Aquia aquifer	Beaufort aquifer	AQ6
Upper Severn confining unit	Correlative units not present in Virginia Coastal Plain	Confining unit	CU5
Severn aquifer		Peedee aquifer	AQ5
Lower Severn confining unit		Confining unit	CU4
Matawan aquifer		Black Creek aquifer	AQ4
Matawan and Brightseat confining units	Brightseat-upper Potomac confining unit	Confining unit	CU3
Magothy and Brightseat aquifers	Brightseat-upper Potomac aquifer	Upper Cape Fear aquifer	AQ3
Patapsco confining unit	Middle Potomac confining unit	Confining unit	CU2
Patapsco aquifer	Middle Potomac aquifer	Lower Cape Fear aquifer	AQ2
Potomac confining unit	Lower Potomac confining unit	Confining unit	CU1
Patuxent aquifer	Lower Potomac aquifer	Lower Cretaceous aquifer	AQ1

TABLE 3.—*Transmissivities and storage coefficients determined for the lower and middle Potomac aquifers and the Brightseat-upper Potomac aquifer*

[ft²/d, feet squared per day]

Aquifer names used in previous reports	Aquifer names used in this report	Selected area or test site	Source of data and method of analysis	Transmissivity (ft²/d) Low	High	Average	Storage coefficient Low	High	Average
Upper Artesian and Principal (Sludyla and others, 1977, Newton and Sludyla, 1979); Mattaponi and Potomac (Cederstrom, 1945, 1957)	Brightseat-upper Potomac aquifer	Franklin (F)	6			1,500			
		Lake Prince (LP)	6			1,500			
		West Point (WP)	10			13,000			$5x10^{-4}$
		Burton Station (BS)	11	3,800	4,500				
	Middle Potomac aquifer	Franklin (F)	1,2,3, and 4	19,000	55,000		$1.1x10^{-3}$	$1.5x10^{-3}$	
			5			19,000	$1.0x10^{-4}$	$6.0x10^{-4}$	
			6			12,000			
			8			19,000			
			9	6,000	24,000				
		Lake Prince (LP)	2	20,000	27,000				$1.5x10^{-3}$
			5			19,000	$1.0x10^{-4}$	$6.0x10^{-4}$	
			6	8,000	12,000				
			7	20,000	23,000				$7.8x10^{-4}$
		Washington's Birthplace (WB)	12			2,000			$2.0x10^{-4}$
		West Point (WP)	10			15,000			$5.0x10^{-4}$
		Ferry Slip (FS)	11	2,600	4,200				
	Lower Potomac aquifer	Franklin (F)	1,2,3, and 4	19,000	55,000		$1.1x10^{-3}$	$1.5x10^{-3}$	
			5			19,000	$1.0x10^{-4}$	$6.0x10^{-4}$	
			6			12,000			
			8			19,000			
			9	6,000	24,000				
		Lake Prince (LP)	2	20,000	27,000				$1.5x10^{-3}$
			5			19,000	$1.0x10^{-4}$	$6.0x10^{-4}$	
			6	8,000	12,000				
			7	20,000	23,000				$7.8x10^{-4}$
		West Point (WP)	10			15,000			$5.0x10^{-4}$

Explanation:

1. Aquifer test recovery data Sinnott (1968), Cooper and Jacob (1946).
2. Aquifer test drawdown data Sinnott (1968), Cooper and Jacob (1946).
3. Aquifer test recovery data Sinnott (1968), Theis (1935).
4. Aquifer test drawdown data Sinnott (1968), Theis (1935).
5. Cosner (1975), model calibration.
6. Layne-Western (1983), analog model.
7. Aquifer test drawdown data Geraghty and Miller (1967), Hantush (1960).
8. Cosner (1975), circumference method.
9. Cosner (1975), potentiometric-slope method.
10. Aquifer test drawdown data Leggette and others (1966), Cooper and Jacob (1946).
11. Aquifer test drawdown data Geraghty and Miller (1979b), Cooper and Jacob (1946).
12. Aquifer test drawdown data Lichtler (1974), Cooper and Jacob (1946).

Letters in parentheses appear on location map of test sites, figure 3.

TABLE 4.—*Vertical hydraulic conductivities of confining units determined by laboratory methods*
[ft, feet; ft/d, foot per day]

City or County	Name of confining unit	U.S. Geological Survey No.	Depth of sample below land surface (ft)	Hydraulic conductivity (ft/d)
Suffolk	Lower Potomac	[1]25-3	978.5-979.5	1.9×10^{-6}
Norfolk	Middle Potomac	[1]24-2	1034-1035	3.4×10^{-6}
Accomac	Nanjemoy-Marlboro	[1]55-10	949-951	1.6×10^{-5}
Northumberland	Nanjemoy-Marlboro	[1]59-12	485-486	2.2×10^{-6}
Gloucester	Nanjemoy-Marlboro	[1]58H4	609	2.0×10^{-5}
Isle of Wight	Calvert	[1]26-5	267-268	9.2×10^{-6}
Norfolk	St. Marys	[1]24-1	538.5-540	2.8×10^{-6}
Gloucester	St. Marys	[2]58H4	248	2.0×10^{-5}
James City	Middle Potomac	[3]56H20	523	2.3×10^{-5}
Suffolk	Yorktown	[3]58B260	42-44.5	3.9×10^{-3}
Suffolk	Yorktown	[3]58B259	60-62	5.9×10^{-4}

[1]Analysis performed by Corps of Engineers, Cincinnati, Ohio. Samples remolded and tests conducted at a series of overburden pressures, with highest pressure equal to or greater than in situ pressure.

[2]Analysis performed by Core Laboratories, Inc., Dallas, Texas.

[3]Analysis performed by Corps of Engineers, Cincinnati, Ohio.

TABLE 5.—*Major withdrawals by aquifer, 1980*

[Mgal/d, million gallons per day; do., ditto. Locations of water users shown in fig. 8]

Water user number	Geographic location	Aquifer	1980 withdrawal (Mgal/d)
020	Franklin	Lower Potomac	10.29
025	West Point	do.	3.79
020	Franklin	Middle Potomac	25.21
023	Williamsburg	do.	1.95
025	West Point	do.	6.57
038	Franklin	do.	1.44
039	Franklin	do.	3.66
045	Tidewater	do.	4.96
048	Tidewater	do.	2.29
068	Henrico County	do.	1.96
071	Alexandria	do.	1.12
016	Smithfield	Brightseat-upper Potomac	1.12
018	Smithfield	do.	1.38
023	Williamsburg	do.	1.33
025	West Point	do.	2.61
028	Urbanna	do.	1.65
045	Tidewater	do.	2.71
054	Williamsburg	do.	1.70
025	West Point	Aquia	.71
434	Southern Maryland	do.	.39
445	Southern Maryland	do.	.21
024	James City	Chickahominy-Piney Point	.35
025	West Point	do.	2.37
309	Edenton	do.	.68
006	Delmarva Peninsula	Yorktown-Eastover	1.55
031	Delmarva Peninsula	do.	.78
300	Elizabeth City	do.	1.30

TABLE 6.—*Average estimated and model-calibrated values of lateral and vertical hydraulic conductivity for aquifers and confining units, respectively*

[In feet per day]

		Average lateral hydraulic conductivity of aquifers	
Model layer	Aquifer name	Initial estimated value	Model-calibrated value
AQ1	Lower Potomac	25.0	41.4
AQ2	Middle Potomac	25.0	51.8
AQ3	Brightseat-upper Potomac	25.0	32.8
AQ4	Aquifer 4	15.0	25.9
AQ5	Aquifer 5	15.0	23.3
AQ6	Aquia	40.0	26.9
AQ7	Chickahominy-Piney Point	35.0	25.1
AQ8	St. Marys-Choptank	10.0	14.7
AQ9	Yorktown-Eastover	20.0	14.7
AQ10	Columbia	15.0	18.1

		Average vertical hydraulic conductivity of confining units	
Model layer	Confining unit name	Initial estimated value	Model-calibrated value
CU1	Lower Potomac	8.50×10^{-4}	3.28×10^{-5}
CU2	Middle Potomac	8.50×10^{-4}	4.06×10^{-5}
CU3	Brightseat-upper Potomac	1.30×10^{-4}	4.41×10^{-5}
CU4	Confining unit 4	1.12×10^{-6}	3.46×10^{-5}
CU5	Confining unit 5	8.64×10^{-6}	7.78×10^{-5}
CU6	Nanjemoy-Marlboro	8.64×10^{-5}	5.36×10^{-5}
CU7	Calvert	8.64×10^{-5}	1.12×10^{-4}
CU8	St. Marys	4.32×10^{-3}	4.15×10^{-4}
CU9	Yorktown	3.46×10^{-3}	8.64×10^{-4}

TABLE 7.—*Minimum and maximum values of transmissivity for aquifers and vertical leakance values for confining units derived by model calibration*

[ft^2/d, feet squared per day; 1/d, inverse day]

Model layer	Aquifer name	Transmissivity (ft^2/d) Minimum	Maximum
AQ1	Lower Potomac	250	12,440
AQ2	Middle Potomac	410	18,145
AQ3	Brightseat-upper Potomac	330	4,175
AQ4	Aquifer 4	210	3,320
AQ5	Aquifer 5	300	1,240
AQ6	Aquia	100	3,830
AQ7	Chickhominy-Piney Point	65	7,640
AQ8	St. Marys-Choptank	210	2,600
AQ9	Yorktown-Eastover	10	4,650
AQ10	Columbia	15	3,000

Model layer	Confining unit name	Vertical leakance (1/d) Minimum	Maximum
CU1	Lower Potomac	1.01×10^{-7}	1.64×10^{-5}
CU2	Middle Potomac	2.54×10^{-7}	4.06×10^{-3}
CU3	Brightseat-upper Potomac	3.90×10^{-7}	4.41×10^{-3}
CU4	Confining unit 4	1.30×10^{-7}	3.84×10^{-6}
CU5	Confining unit 5	4.89×10^{-7}	7.78×10^{-6}
CU6	Nanjemoy-Marlboro	8.25×10^{-8}	2.68×10^{-3}
CU7	Calvert	2.67×10^{-7}	5.60×10^{-3}
CU8	St. Marys	1.14×10^{-6}	3.19×10^{-3}
CU9	Yorktown	4.80×10^{-6}	1.08×10^{-3}

TABLE 8.—*Average withdrawal from each aquifer used in the calibrated model, by pumping period from 1891 to 1980*
[In million gallons per day]

Model layer	Aquifer	Pumping period 1	2	3	4	5	6	7	8	9	10
		1891-1920	1921-1939	1940-1945	1946-1952	1953-1957	1958-1964	1965-1967	1968-1972	1973-1977	1978-1980
1	Lower Potomac	0.01	0.29	2.14	3.69	6.13	9.19	11.55	14.56	14.91	14.22
2	Middle Potomac	5.34	8.38	12.73	15.30	20.34	31.06	38.78	51.09	54.48	55.91
3	Brightseat-upper Potomac	5.46	6.06	11.43	11.99	10.59	13.14	17.28	20.76	19.26	19.42
4	Aquifer 4	.01	.25	.26	.26	.25	.24	.22	.56	.20	.20
5	Aquifer 5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
6	Aquia	.06	.28	1.39	1.70	1.61	1.51	2.05	2.52	2.85	2.82
7	Chickahominy-Piney Point	.16	.90	1.91	2.28	3.01	3.52	4.44	4.15	3.84	4.19
8	St. Marys-Choptank	.00	.00	.00	.00	.00	.00	.00	.00	.02	.16
9	Yorktown-Eastover	.03	.32	.50	.93	1.16	1.54	2.59	5.81	8.46	8.25
10	Columbia	.00	.00	.00	.00	.00	.01	.02	.02	.03	.05
	Totals	11.07	16.48	30.36	36.15	43.09	60.21	76.93	99.47	104.05	105.22

TABLE 9.—*Computed lateral boundary fluxes*

[Values, in million gallons per day, are not intended to imply accuracy to the precision shown. do., ditto]

Simulated conditions		Lower Potomac aquifer Flux Into	Out of	Net	Middle Potomac aquifer Flux Into	Out of	Net	Brightseat-upper Potomac aquifer Flux Into	Out of	Net	Aquifer 4 Flux Into	Out of	Net	Aquifer 5 Flux Into	Out of	Net
Prepumping		0.36	0.04	0.32	0.17	1.21	-1.14	0.27	0.30	-0.12	0.05	0.24	-0.19	0.00	0.08	-0.08
Pumping period 1	1891-1920	.36	.04	.32	.17	1.21	-1.14	.27	.39	-.12	.05	.24	-.19	.00	.08	-.08
do. 2	1921-1939	.00	1.32	-1.32	.21	.91	-.70	.27	.38	-.11	.06	.22	-.16	.00	.08	-.08
do. 3	1940-1945	.00	2.97	-2.97	.26	.81	-.55	.28	.39	-.11	.14	.21	-.07	.00	.08	-.08
do. 4	1946-1952	.00	4.82	-4.82	.44	.55	-.11	.28	.35	-.07	.14	.20	-.06	.00	.07	-.07
do. 5	1953-1957	.00	3.17	-3.17	.44	.63	-.19	.26	.38	-.12	.14	.20	-.66	.00	.07	-.07
do. 6	1958-1964	.00	2.70	-2.70	.50	.71	-.21	.23	.44	-.21	.12	.21	-.09	.00	.07	-.07
do. 7	1965-1967	.00	2.28	-2.28	.75	.75	-.00	.22	.55	-.33	.10	.20	-.10	.00	.06	-.06
do. 8	1968-1972	.00	2.83	-2.83	1.00	.69	.31	.22	.63	-.41	.08	.21	-.13	.00	.05	-.05
do. 9	1973-1977	.00	3.85	-3.85	1.36	.94	.42	.20	.75	-.55	.09	.23	-.14	.00	.05	-.05
do. 10	1978-1980	.00	4.27	-4.27	1.37	1.17	.20	.19	.86	-.67	.09	.26	-.17	.00	.04	-.04

Simulated conditions		Aquia aquifer Flux Into	Out of	Net	Chickahominy-Piney Point aquifer Flux Into	Out of	Net	St. Marys-Choptank aquifer Flux Into	Out of	Net	Yorktown-Eastover aquifer Flux Into	Out of	Net	Columbia Aquifer Flux Into	Out of	Net
Prepumping		0.15	0.78	-0.63	0.20	1.60	-1.40	0.14	0.39	-0.25	0.33	0.90	-0.67	0.08	0.67	-0.59
Pumping period 1	1891-1920	.15	.78	-.63	.20	1.60	-1.40	.14	.39	-.25	.33	.90	-.57	.08	.67	-.59
do. 2	1921-1939	.15	.76	-.61	.20	1.57	-1.37	.14	.38	-.24	.33	.91	-.58	.08	.67	-.59
do. 3	1940-1945	.15	.73	-.58	.20	1.54	-1.34	.15	.39	-.24	.32	.90	-.58	.08	.67	-.59
do. 4	1946-1952	.12	.75	-.63	.17	1.55	-1.38	.15	.39	-.24	.32	.90	-.58	.08	.67	-.59
do. 5	1953-1957	.12	.75	-.63	.16	1.55	-1.39	.15	.39	-.24	.32	.90	-.58	.08	.67	-.59
do. 6	1958-1964	.10	.80	-.70	.15	1.60	-1.45	.15	.38	-.23	.32	.90	-.58	.08	.67	-.59
do. 7	1965-1967	.07	1.00	-.93	.13	1.62	-1.47	.16	.38	-.22	.32	.90	-.58	.08	.66	-.58
do. 8	1968-1972	.05	.90	-.85	.12	1.60	-1.48	.17	.37	-.20	.32	.89	-.57	.08	.66	-.58
do. 9	1973-1977	.05	1.03	-.98	.11	1.63	-1.52	.19	.37	-.18	.40	.88	-.48	.08	.67	-.59
do. 10	1978-1980	.04	1.02	-.98	.11	1.61	-1.50	.20	.37	-.17	.38	.88	-.50	.08	.67	-.59

TABLE 10.—*Computed leakage rates across confining units into and out of the confined flow system*
[Values, in million gallons per day, are not intended to imply accuracy to the precision shown. do., ditto]

Simulated Conditions		Lower Potomac confining-unit: Volumetric leakage rate			Middle Potomac confining-unit: Volumetric leakage rate			Brightseat-upper Potomac confining-unit: Volumetric leakage rate			Confining unit 4: Volumetric leakage rate			Confining unit 5: Volumetric leakage rate		
		Into	Out of Lower Potomac aquifer	Net	Into	Out of Middle Potomac aquifer	Net	Into	Out of Brightseat-upper Potomac aquifer	Net	Into	Out of Aquifer 4	Net	Into	Out of Aquifer 5	Net
Prepumping		1.96	1.71	−0.25	31.38	30.56	0.82	15.65	19.31	−3.66	1.55	3.40	−1.85	0.00	0.06	−0.06
Pumping Period 1	1891–1920	1.96	2.45	−.49	33.48	27.76	5.72	18.34	15.21	3.13	1.65	2.97	−1.32	.00	.05	−.05
do. 2	1921–1939	2.91	1.50	1.41	35.43	25.12	10.31	19.94	13.79	6.15	1.80	2.64	−.84	.00	.05	−.05
do. 3	1940–1945	5.65	.95	4.68	40.18	22.76	17.42	25.54	11.39	14.15	2.20	1.92	.28	.00	.04	−.04
do. 4	1946–1952	8.77	.54	8.23	43.58	20.45	23.13	27.93	10.62	17.31	2.01	1.98	.03	.00	.04	−.04
do. 5	1953–1957	9.36	.23	9.13	47.96	18.63	29.33	31.28	9.77	21.51	2.20	1.65	.55	.00	.03	−.03
do. 6	1958–1964	11.81	.21	11.60	58.56	15.97	42.59	41.24	8.51	32.73	2.88	1.03	1.85	.01	.02	−.01
do. 7	1965–1967	13.30	.39	12.91	66.39	15.87	50.12	49.50	7.97	41.53	3.48	.77	2.71	.01	.02	−.01
do. 8	1968–1972	17.08	.42	16.56	80.02	13.50	66.52	63.43	7.24	56.19	5.16	.40	4.76	.03	.00	.03
do. 9	1973–1977	18.65	.25	18.40	83.80	11.71	72.09	66.14	6.99	59.15	5.17	.42	4.75	.02	.00	.02
do. 10	1978–1980	18.59	.20	18.39	84.89	10.85	74.04	66.89	6.46	60.43	5.33	.39	4.94	.02	.00	.02

Simulated Conditions		Nanjemoy-Marlboro confining unit: Volumetric leakage rate			Calvert confining unit: Volumetric leakage rate			St. Marys confining unit: Volumetric leakage rate			Yorktown confining unit: Volumetric leakage rate			Volumetric leakage rate		
		Into	Out of Aquia aquifer	Net	Into	Out of Chickahominy-Piney Point aquifer	Net	Into	Out of St. Marys-Choptank aquifer	Net	Into	Out of Yorktown-Eastover aquifer	Net	Into	Out of Confined system	Net
Prepumping		21.30	34.52	−13.22	29.61	35.21	−5.60	8.12	9.40	−1.28	92.23	109.71	−17.48	118.73	124.03	−5.30
Pumping Period 1	1891–1920	24.10	28.68	−4.58	31.90	31.28	.62	8.37	8.93	−.56	96.66	103.68	−7.02	123.30	117.68	5.62
do. 2	1921–1939	26.00	26.15	.15	33.47	29.36	4.11	8.66	8.65	.01	99.12	100.55	−1.43	126.37	113.80	12.57
do. 3	1940–1945	32.06	21.88	10.17	37.55	25.28	12.27	8.92	8.14	.78	103.56	92.93	10.63	132.08	104.85	27.23
do. 4	1946–1952	34.80	19.74	15.06	39.23	23.62	15.61	9.06	7.88	1.17	107.31	90.71	16.61	136.66	101.38	35.28
do. 5	1953–1957	37.37	18.74	18.63	41.06	22.37	18.69	9.22	7.62	1.60	108.64	88.14	20.50	138.38	98.77	39.61
do. 6	1958–1964	45.43	15.85	29.58	45.75	19.49	26.26	9.83	6.84	2.99	117.65	82.46	36.19	149.45	91.10	58.35
do. 7	1965–1967	50.60	17.08	33.53	52.97	14.22	38.75	10.27	6.45	3.82	121.74	77.06	44.68	154.74	84.83	69.91
do. 8	1968–1972	66.44	11.45	54.99	58.99	14.57	44.42	11.22	5.91	5.31	136.96	69.54	37.42	171.50	76.24	95.26
do. 9	1973–1977	69.90	10.68	59.22	60.81	13.63	47.18	11.61	5.80	5.81	140.22	68.33	71.89	175.48	74.48	101.00
do. 10	1978–1980	70.31	10.38	59.93	61.15	13.42	47.73	11.83	5.69	6.14	140.77	67.15	73.62	177.02	72.74	104.28

TABLE 11.—*Model-computed ground-water budgets*

[Values, in million gallons per day, are not intended to imply accuracy to the precision shown]

Sources	MODEL-COMPUTED VOLUMETRIC FLOW RATES FOR PREPUMPING SIMULATION
Recharge from precipitation	9,237.81
Lateral boundary inflow	1.76
Ground-water flow from streams and coastal water bodies	.00
Discharges	
Lateral boundary outflow	6.31
Ground-water flow into streams and coastal-water bodies	9,233.93

MODEL-COMPUTED VOLUMETRIC FLOW RATES FOR PUMPING SIMULATION

	Pumping Period									
	1 (10957.2 days) 1891-1920	2 (6939.8 days) 1921-1939	3 (2191.0 days) 1940-1945	4 (2556.7 days) 1946-1952	5 (1826.4 days) 1953-1957	6 (2556.7 days) 1958-1964	7 (1095.7 days) 1965-1967	8 (1826.4 days) 1968-1972	9 (1826.4 days) 1973-1977	10 (1095.7 days) 1978-1980
Sources										
Water released from aquifer storage	0.00	0.09	2.92	1.39	1.82	2.62	7.28	6.57	2.80	1.60
Lateral boundary inflow	1.76	1.45	1.58	1.71	1.67	1.67	1.85	2.05	2.49	2.46
Recharge from precipitation	9,237.81	9,237.81	9,237.81	9,237.81	9,237.81	9,237.81	9,237.81	9,237.81	9,237.91	9,237.91
Ground-water flow from streams and coastal water bodies	.00	.00	.00	.00	.00	.00	.07	.26	.48	.53
Discharges										
Water entering aquifer storage	.00	.00	.02	.00	.03	.00	.00	.00	.10	.11
Lateral boundary outflow	6.30	7.22	8.69	10.23	8.72	8.48	8.45	8.86	10.41	11.50
Ground-water withdrawal from wells	10.88	16.49	29.94	35.05	42.52	60.23	76.75	99.42	104.02	105.13
Ground-water flow into streams and coastal water bodies	9,224.24	9,217.13	9,204.85	9,197.09	9,191.28	9,174.47	9,162.84	9,139.57	9,129.88	9,127.29

Note: The difference between total sources and discharges is due to numerical truncation errors in the digital simulation.

TABLE 12.—*Summary of sensitivity tests*

[ft/d, foot per day; ft, foot]

Hydraulic characteristic	Range of change	Actual value	Change in water levels, in feet: Range in deviation in hydrographs of middle Potomac aquifer from calibrated hydrographs in 1980	Change in water levels, in feet: Hydrographs of selected confined aquifers shown in figures 76-79; range in deviation from calibrated hydrographs in 1980
Transmissivity of middle Potomac aquifer	Increase 100% Decrease 50%	Variable	+20 to +75 -15 to -125	Not applicable
Vertical hydraulic conductivity of middle Potomac confining unit	Increase 100% Decrease 50%	8.12×10^{-5} ft/d 2.03×10^{-5} ft/d	+10 to +30 -30 to -60	Not applicable
Storage coefficient of all confined aquifers	Increase 1 order of magnitude Decrease 1 order of magnitude	1.0×10^{-3} 1.0×10^{-5}	Not applicable	+5 to +15 Less than 5
Specific storage coefficient of all confining units		1.0×10^{-4}/ft 1.0×10^{-6}/ft	Not applicable	+15 to +40 Less than 5[1]

[1]Hydrographs for calibrated model which neglected water released from storage in the confining units during transient simulations (specific storage = 0/ft) and the assumed specific storage of the confining unit (1.0×10^{-6}/ft) are shown as same line in figures 78 and 79.

TABLE 13.—*Specific storage and computed storage coefficients of confining units used for sensitivity tests*

Model layer	Confining unit	Estimated average confining unit thickness (feet)	Computed storage coefficient (dimensionless): Specific storage 1.0×10^{-4} ft^{-1}	Computed storage coefficient (dimensionless): Specific storage 1.0×10^{-6} ft^{-1}
CU1	Lower Potomac	25	2.50×10^{-3}	2.50×10^{-5}
CU2	Middle Potomac	40	4.00×10^{-3}	4.00×10^{-5}
CU3	Brightseat-upper Potomac	35	3.50×10^{-3}	3.50×10^{-5}
CU4	Confining unit 4	25	2.50×10^{-3}	2.50×10^{-5}
CU5	Confining unit 5	25	2.50×10^{-3}	2.50×10^{-5}
CU6	Nanjemoy-Marlboro	100	1.00×10^{-2}	1.00×10^{-4}
CU7	Calvert	125	1.25×10^{-2}	1.25×10^{-4}
CU8	St. Marys	90	9.00×10^{-3}	9.00×10^{-5}
CU9	Yorktown	50	5.00×10^{-3}	5.00×10^{-5}